Exoplanet Science with a Microlensing Survey: Potential of the NRO Telescope and Trade Considerations

1st AFTA SDT Meeting

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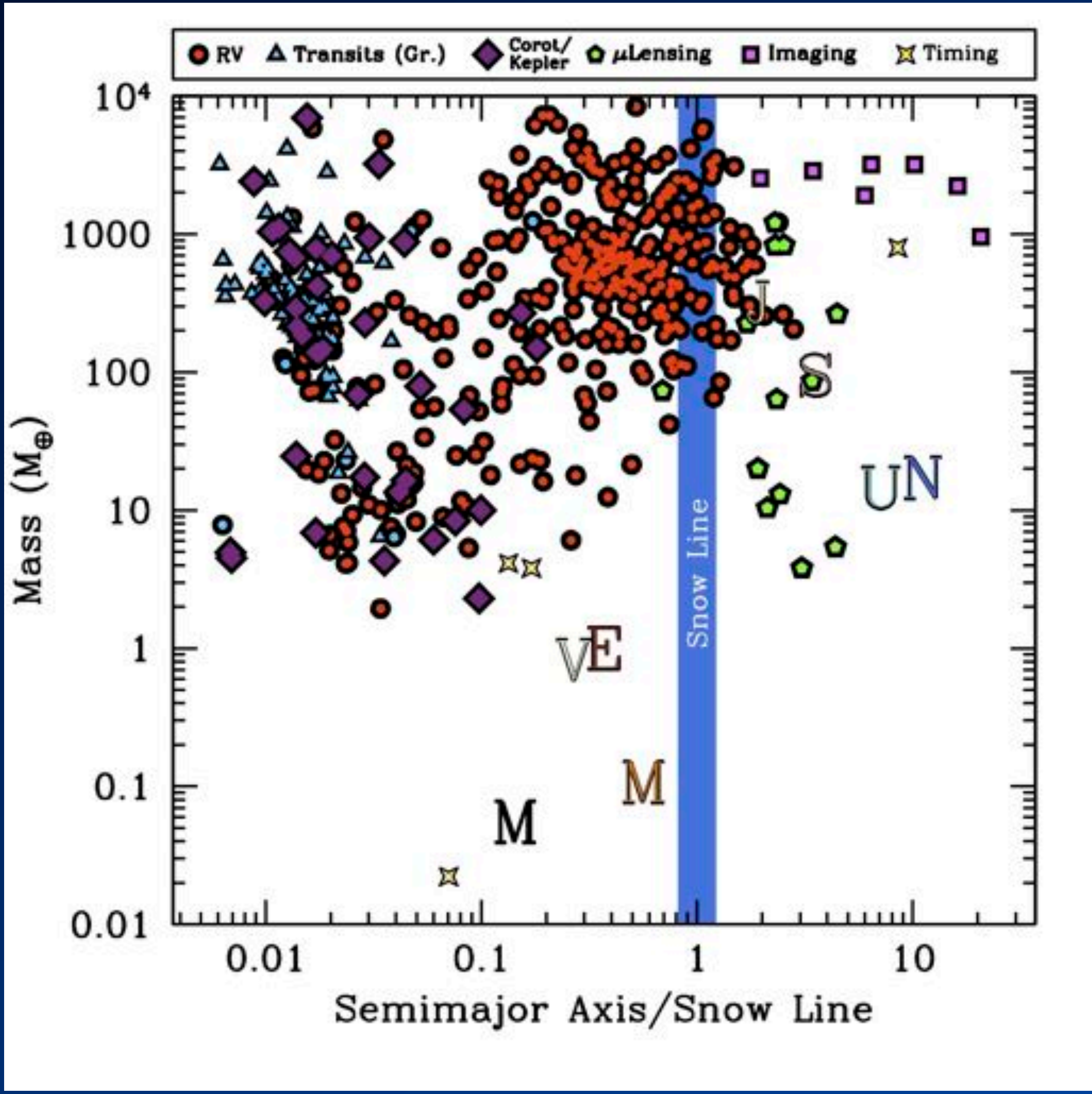
Science Motivation.

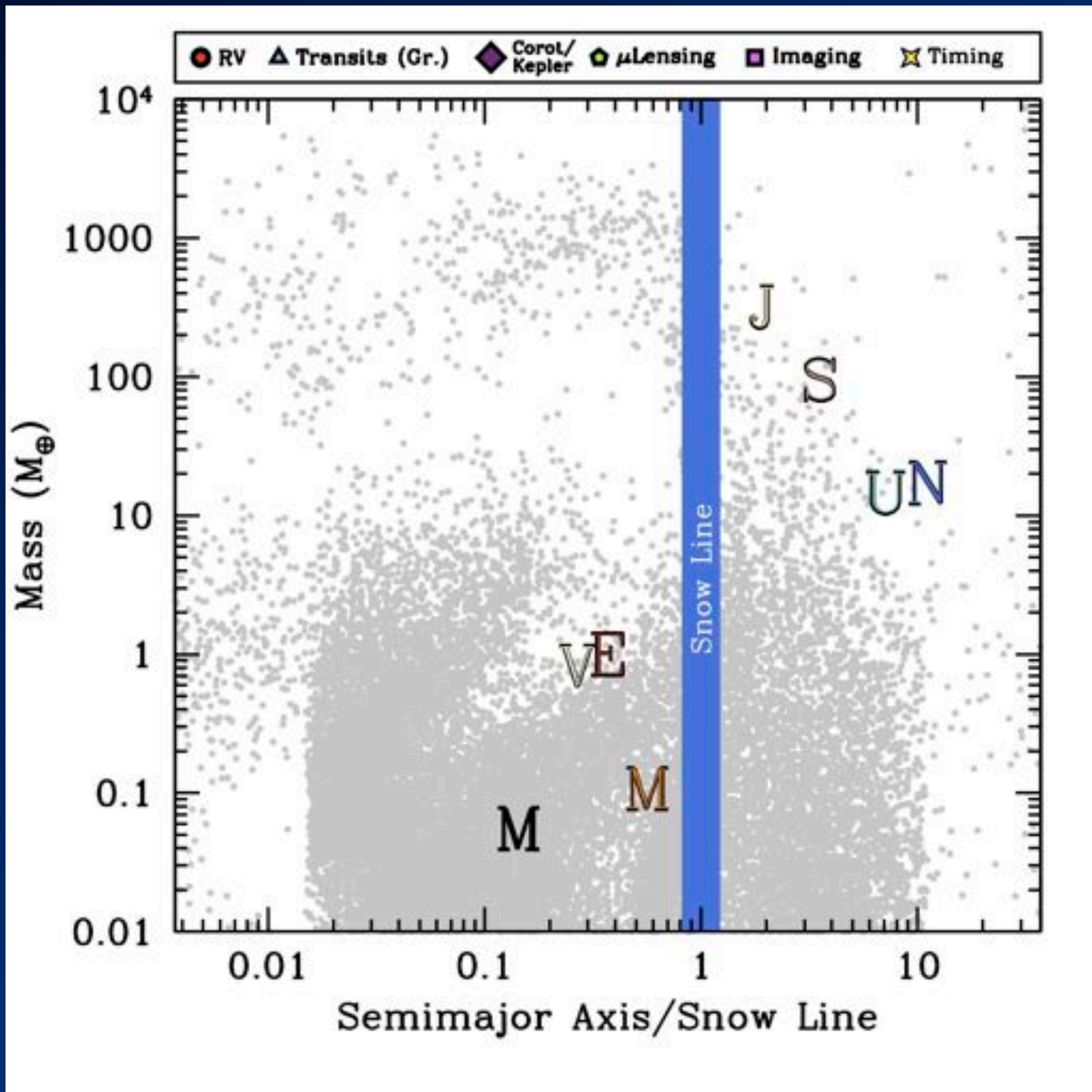
Planet Formation.

Must understand the physical processes by which micron-sized grains in protoplanetary disks grow by $10^{\sim 13\text{-}14}$ in size and $10^{\sim 38\text{-}41}$ in mass.

Hard!

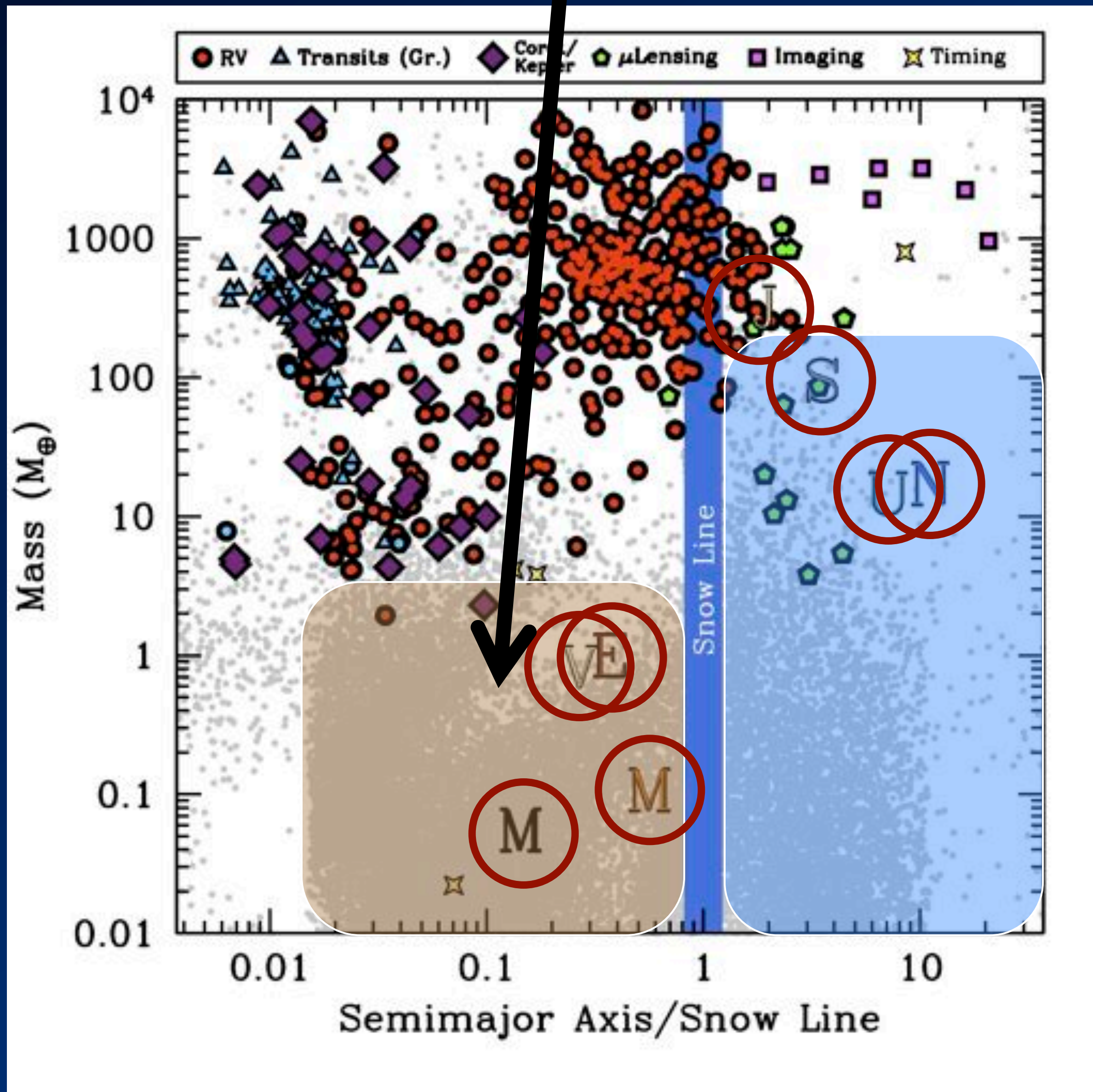
Strange New Worlds.




RV
Transits (Gr.)
Corot/ Kepler
μLensing
Imaging
Timing
Mass ($M_\oplus$)
10^4
1000
100
10
1
0.1
0.01
0.01
0.1
1
10
Semimajor Axis/Snow Line
Snow Line
J
S
U
N
V
E
M
M

(Ida & Lin)

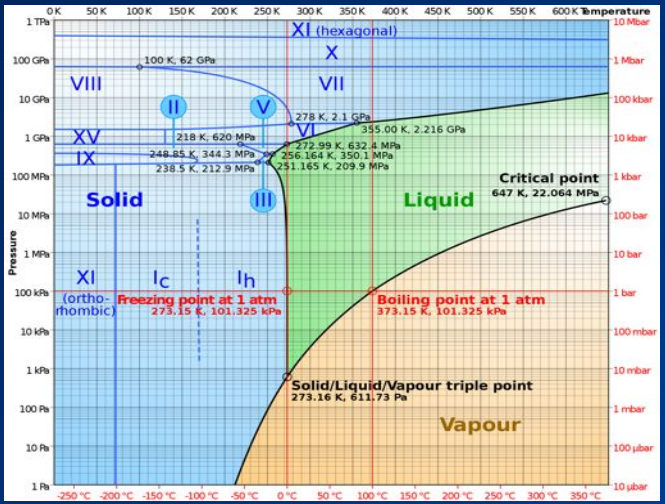
***Kepler* is revolutionizing our understanding of exoplanets here!**

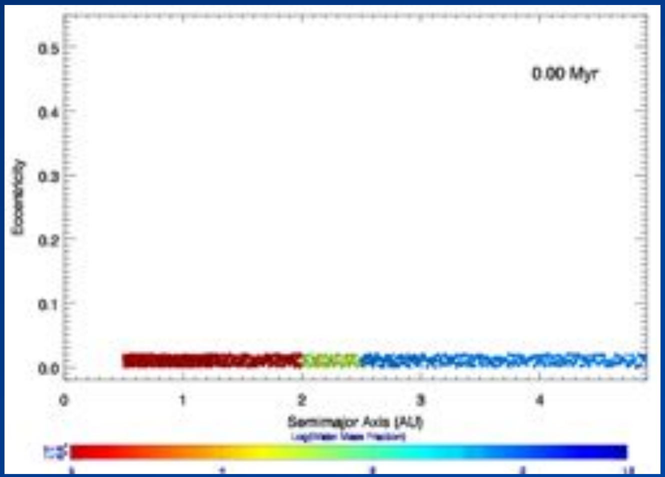


Understanding Habitability.

Knowledge of Demographics Beyond the Snow Line is Required.

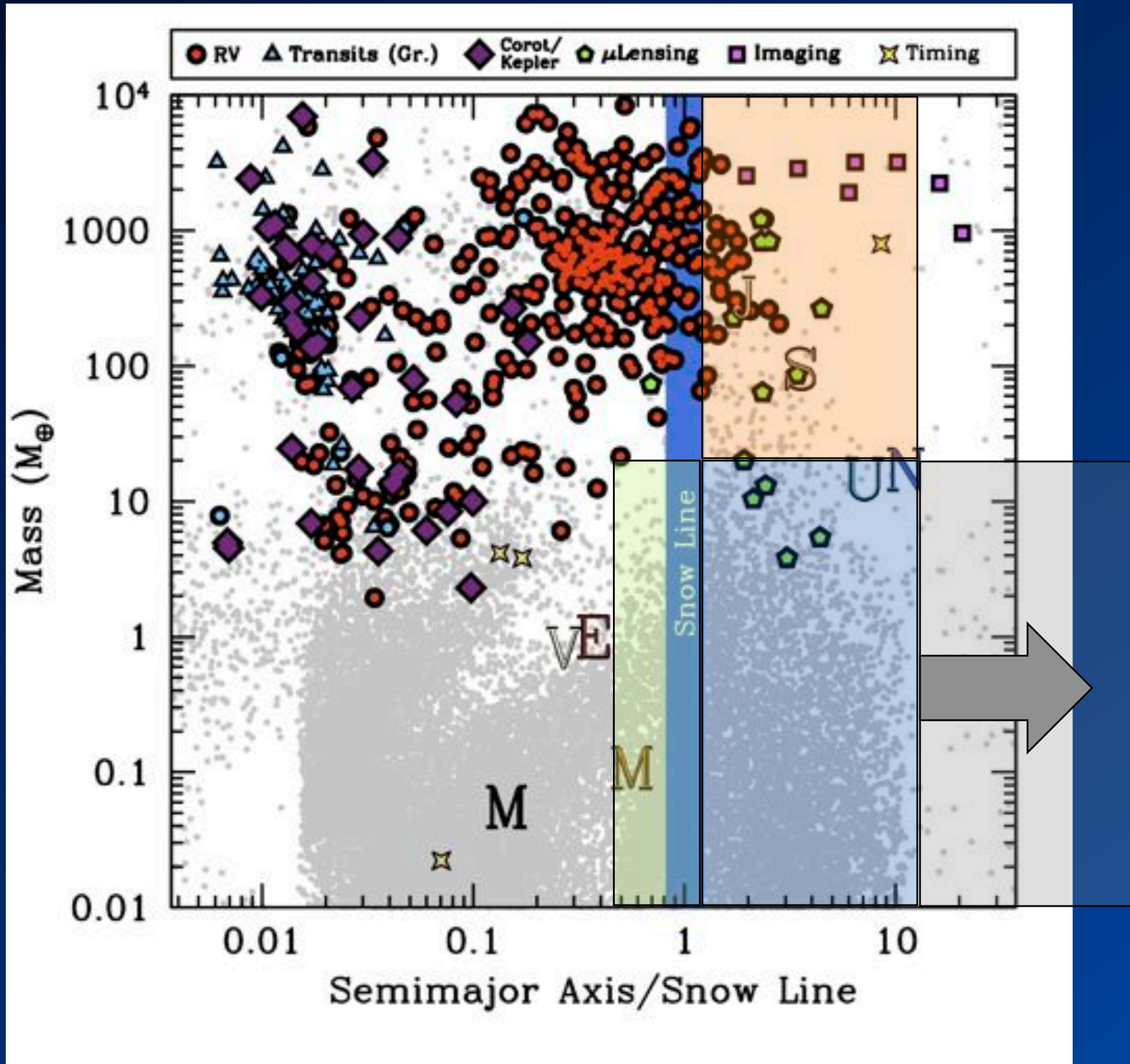
- Water comes from outer solar system.
  - For *in situ* formation, material that accreted to form rocky planets in the HZ was likely *dry*.
- Inner and outer regions coupled.
  - Giant planets likely formed first.
  - Presence (or not) and properties of outer gas giants has a significant effect on inner planets

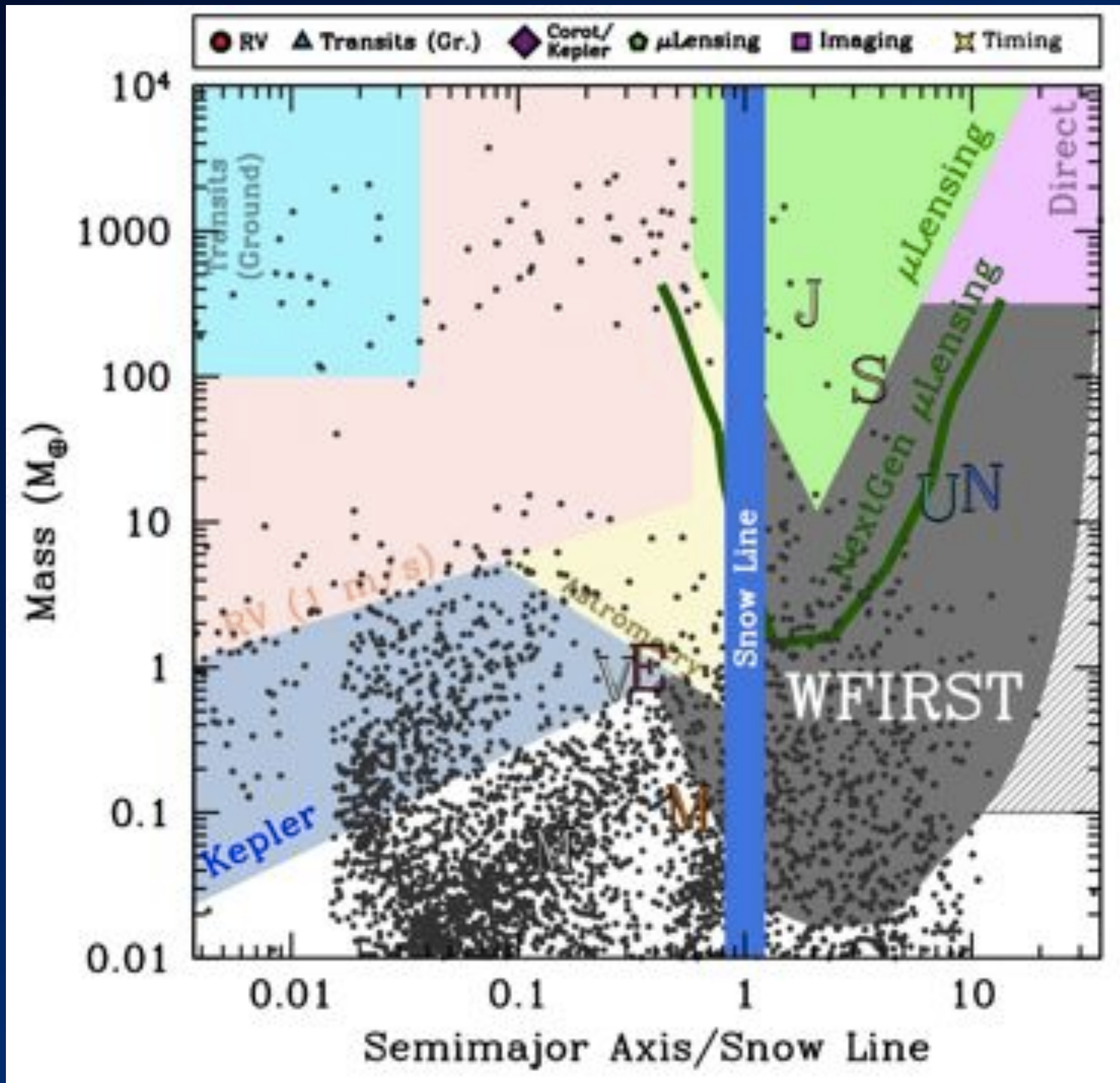




(Raymond et al. 2006,)

To the snow line... and beyond!

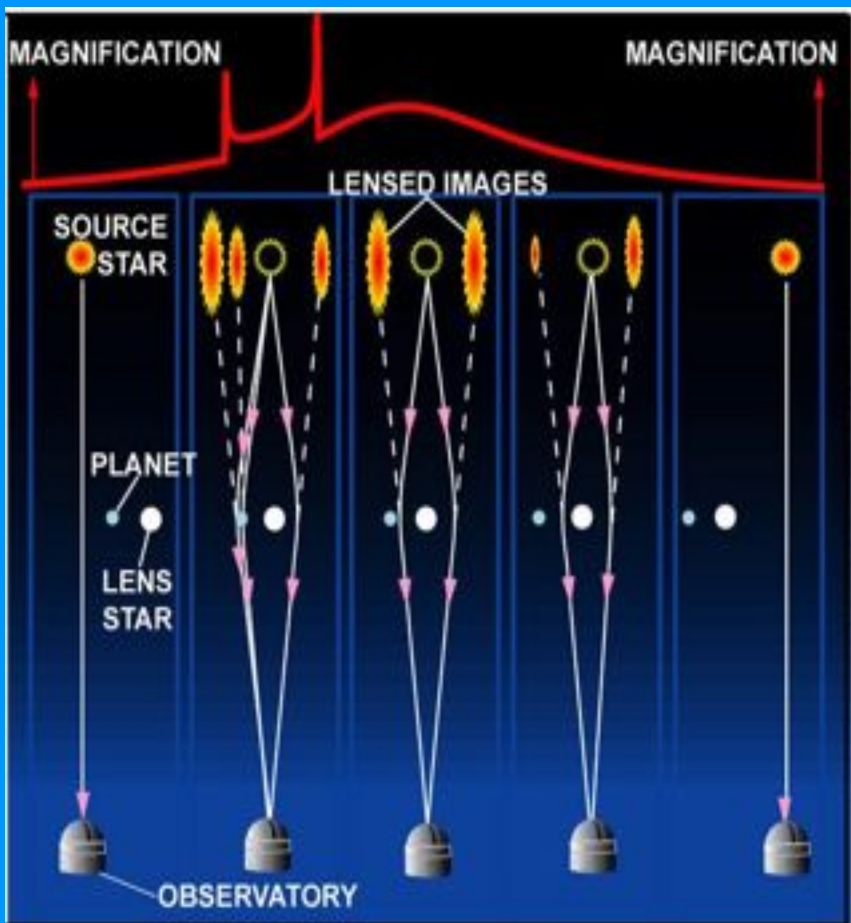


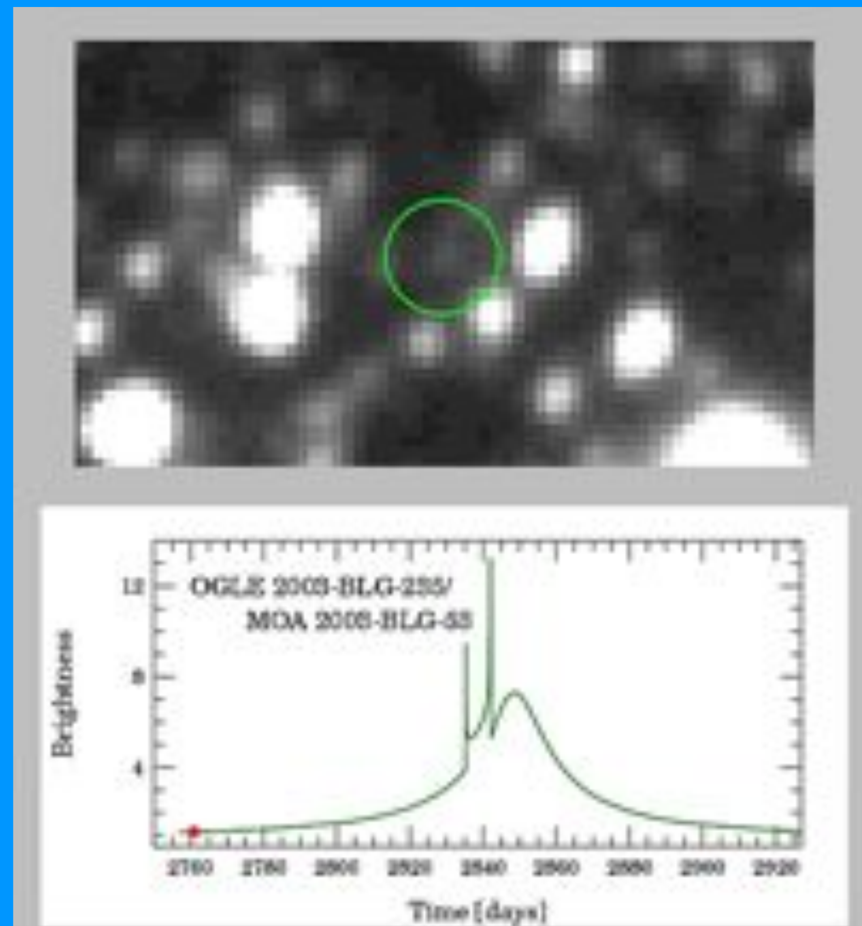


RV
Transits (Gr.)
Corot/ Kepler
μLensing
Imaging
Timing
Mass ($M_\oplus$)
Semimajor Axis/Snow Line
Transits (Ground)
RV (1 m/s)
Astrometry
Kepler
Snow Line
μLensing
NextGen μLensing
Direct
WFIRST
J
S
UN
E
V
M

Microlensing.

Microlensing Basics.





The Good and the Bad (and the Ugly).

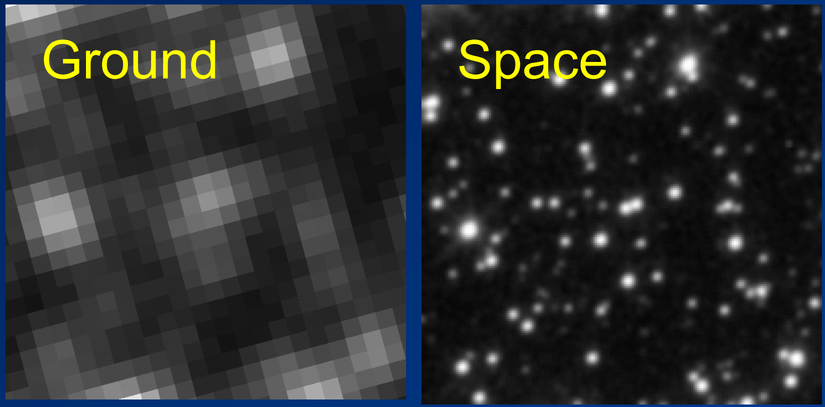
- The Good.
  - Sensitive to:
    - Planets beyond the snow line.
    - Free-floating planets.
    - Very low-mass planets.
  - Large signals.
- The Bad.
  - Rare and Unpredictable.
  - Short time scale.
- The Ugly.
  - Difficult (but not impossible!) to estimate primary mass.

Requirements.

- Monitor hundreds of millions of bulge stars continuously on a time scale of ~10 minutes.
  - Event rate ~10^{-5}/year/star.
  - Detection probability ~0.1-1%.
  - Shortest features are ~30 minutes.
- Relative photometry of a few %.
  - Deviations are few – 10%.
- Main sequence source stars for smallest planets.
- Resolve background stars for primary mass determinations.

Ground vs. Space.

- Infrared.
  - More photons.
  - More extincted fields.
  - Smaller sources.
- Resolution.
  - Low-magnification events.
  - Isolate light from the lens star.
- Visibility.
  - Complete coverage.
- Smaller systematics.
  - Better characterization.
  - Robust quantification of sensitivities.



The field of microlensing event MACHO 96-BLG-5 (Bennett & Rhie 2002)

Science potentially enabled from space: sub-Earth mass planets, habitable zone planets, free-floating Earth-mass planets, host star characterization.

Yields.

- Yields determined by:
  - Total number of stars monitored.
  - Photon rate.
  - Total observing time.
- Primary hardware dependencies:
  - FOV.
  - Aperture.
  - Bandpass (total throughput + red cutoff).
  - Resolution (background).
  - Pointing constraints.
- Secondary hardware dependencies:
  - Data downlink.

Characterization.

- Characterizing lens stars:
  - Measure angular source size.
  - Resolve unrelated stars.
  - Measure proper motion or centroid shifts.
  - Measure parallax.
- Primary hardware dependencies:
  - Second filter.
  - Effective resolution.
  - PSF stability.
  - Baseline of observations.
  - Aperture.
  - Dwell time.
- Secondary hardware dependencies:
  - Shutter changes.

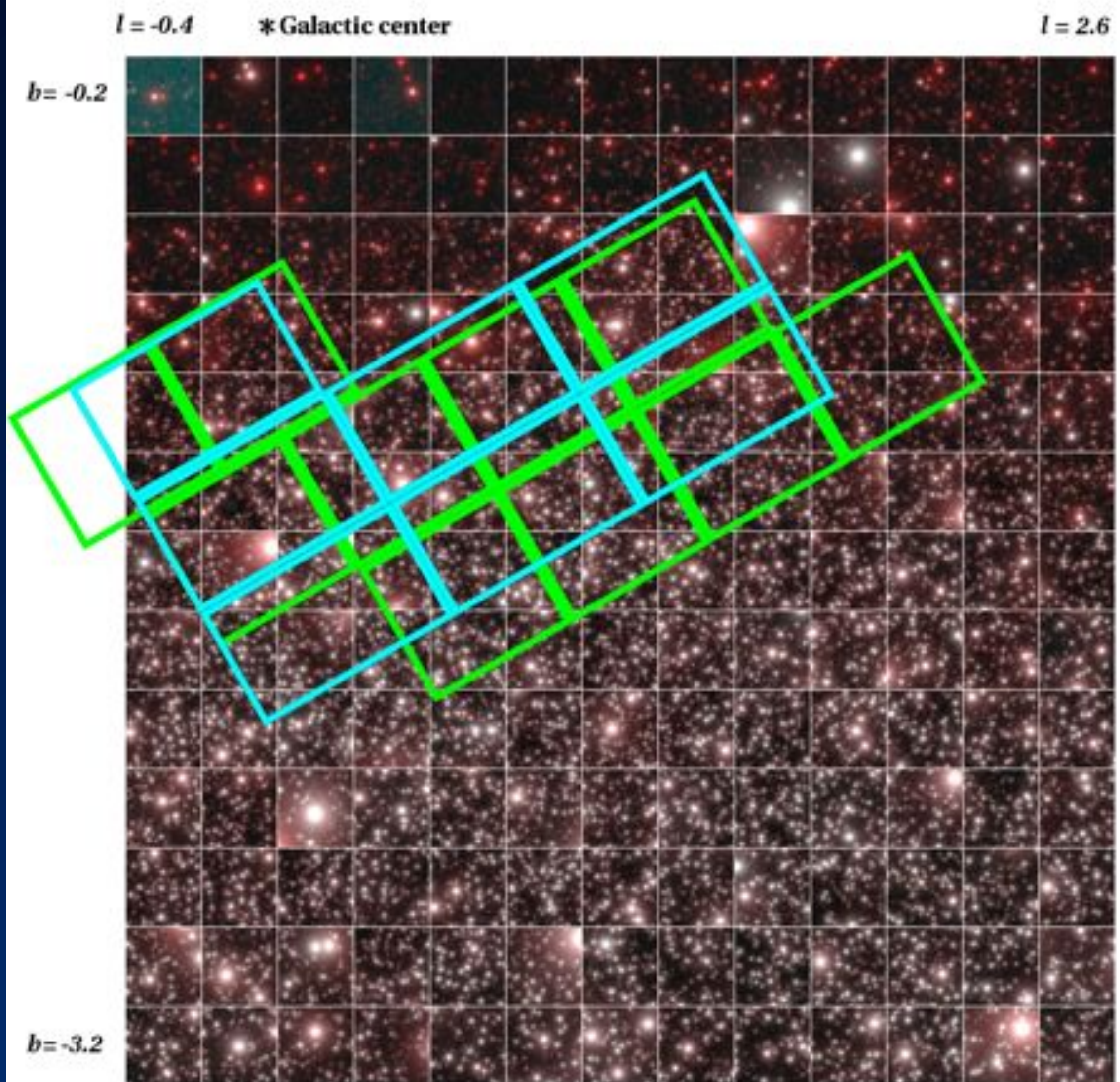
Yields: NRO vs DRM1 vs DMR2.

M/M_{Earth}	DRM1	DRM2	NRO
0.1	30	29	82
1	239	279	379
10	794	918	1322
100	630	733	1067
1000	367	442	509
10,000	160	199	205
Total	2221	2600	3564

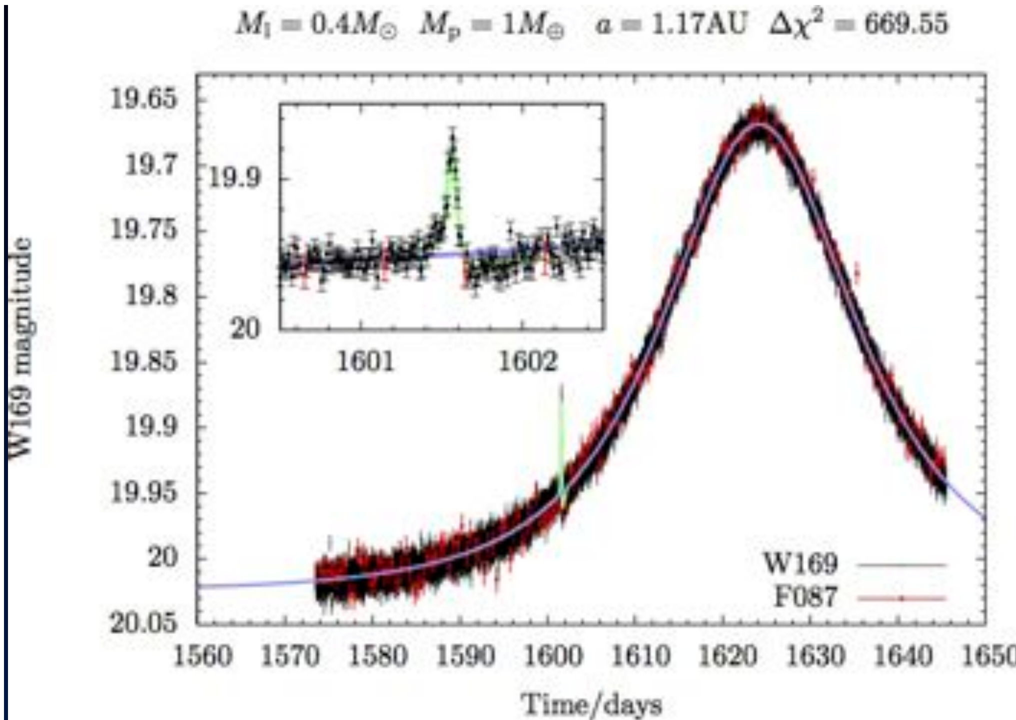
- Total time = 432 days, same FOV.
- Yield ~propto FOV
- Yield ~propto (photon rate)$^{\alpha}$, with α~0.3 to 1.2
- DRM2 versus DMR1:
  - DMR2 FOV 1.55 larger, photon rate 0.72 of DMR1
- NRO versus DRM1:
  - DMR1 FOV = NRO FOV, photon rate 2.28 times DMR1
  - Assumes same FOV and some total observing time!

Better Yield Estimates.

- Current running new simulations:
  - Based on Besançon model.
  - Using different pixel sizes.
  - 1.5μm cutoff.
- Preliminary results
  - 40-50% higher yields for massive planets.
  - Substantially larger yields for low-mass planets.

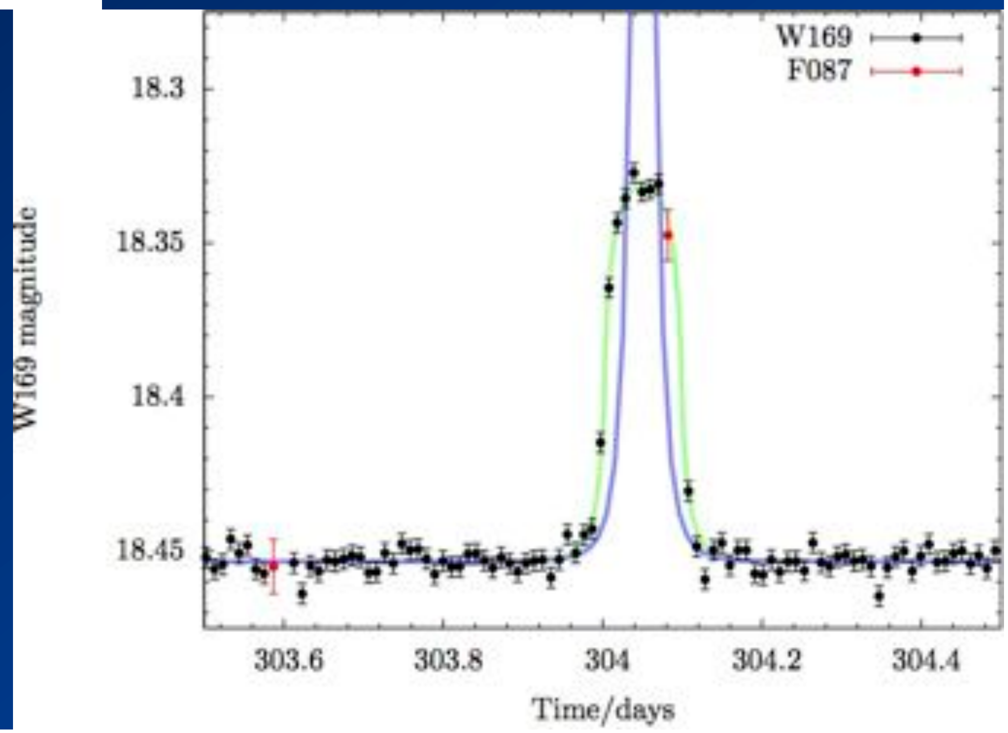


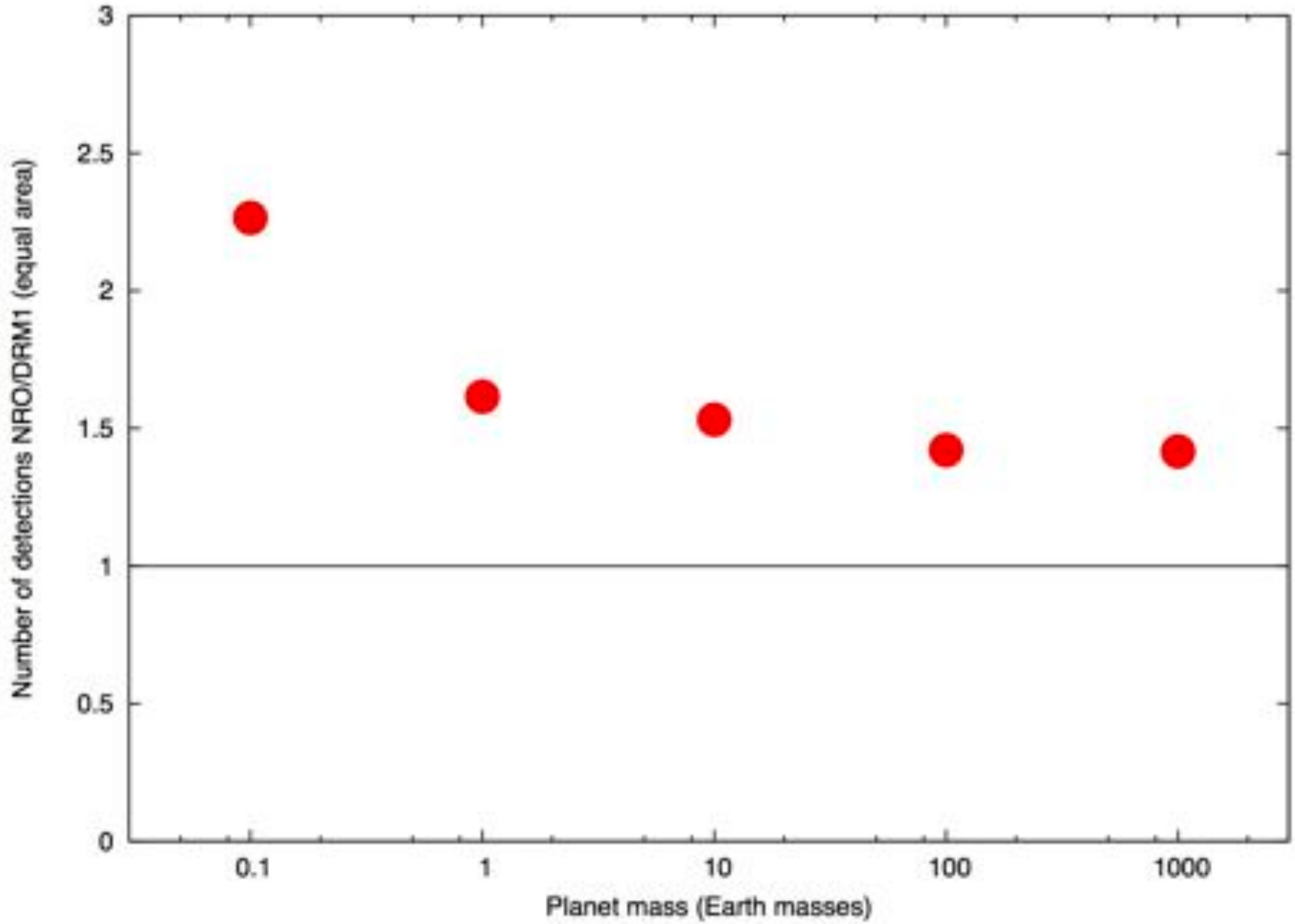
l = -0.4
∗ Galactic center
l = 2.6
b= -0.2
b= -3.2



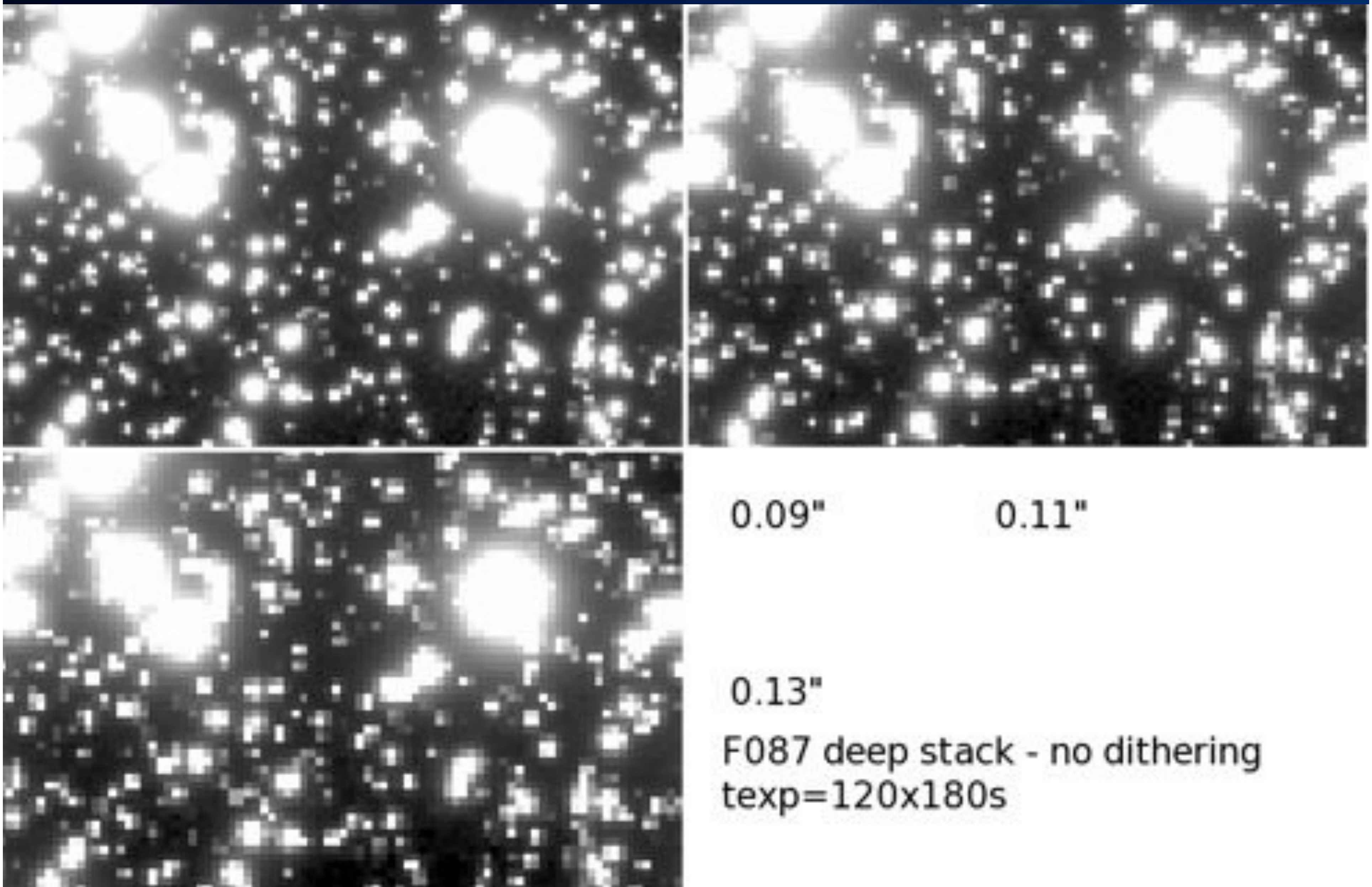
Earth-mass Planet

Free Floating Earth





Number of detections NRO/DRM1 (equal area)
Planet mass (Earth masses)
0
0.5
1
1.5
2
2.5
3
0.1
1
10
100
1000

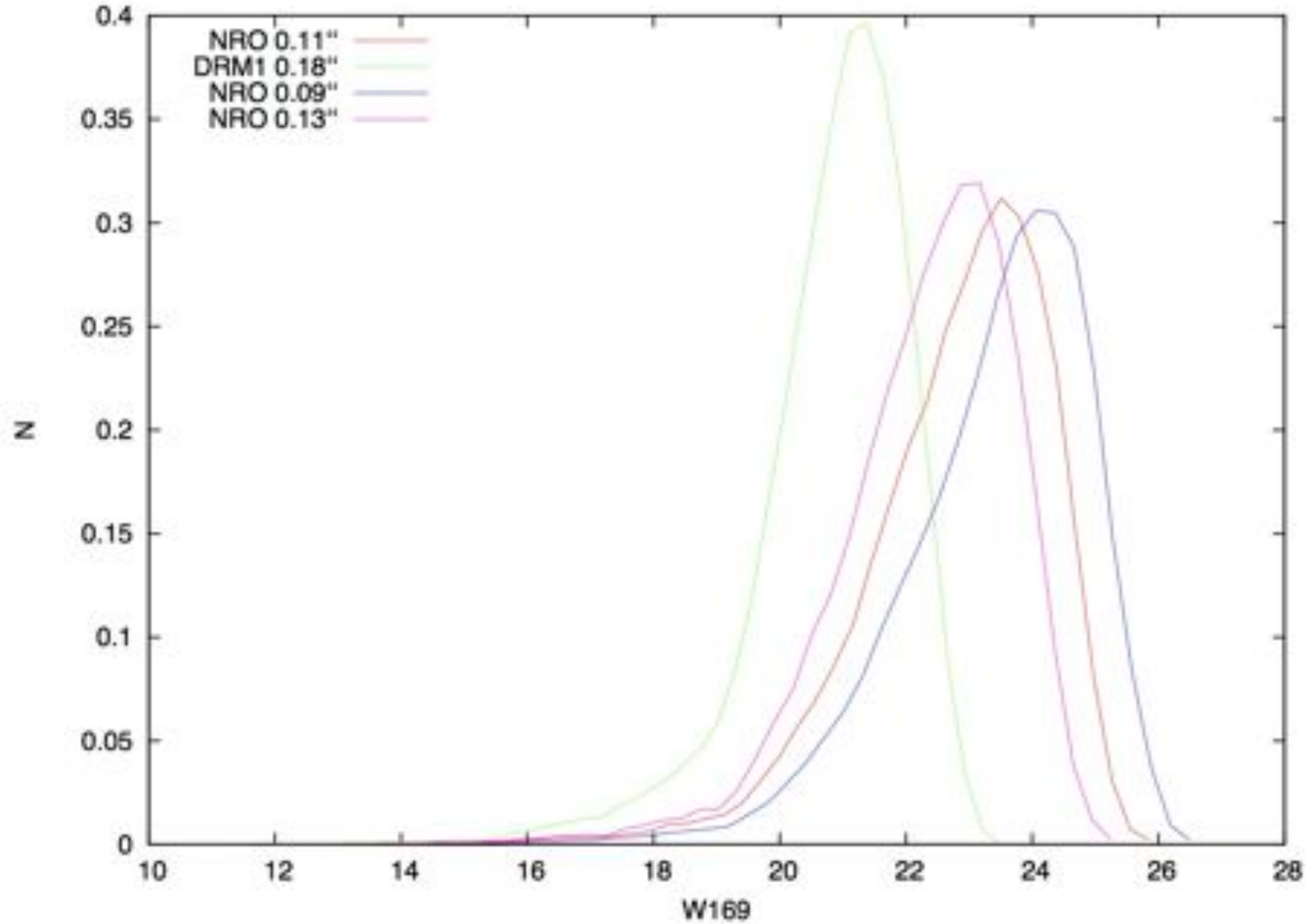


0.09"

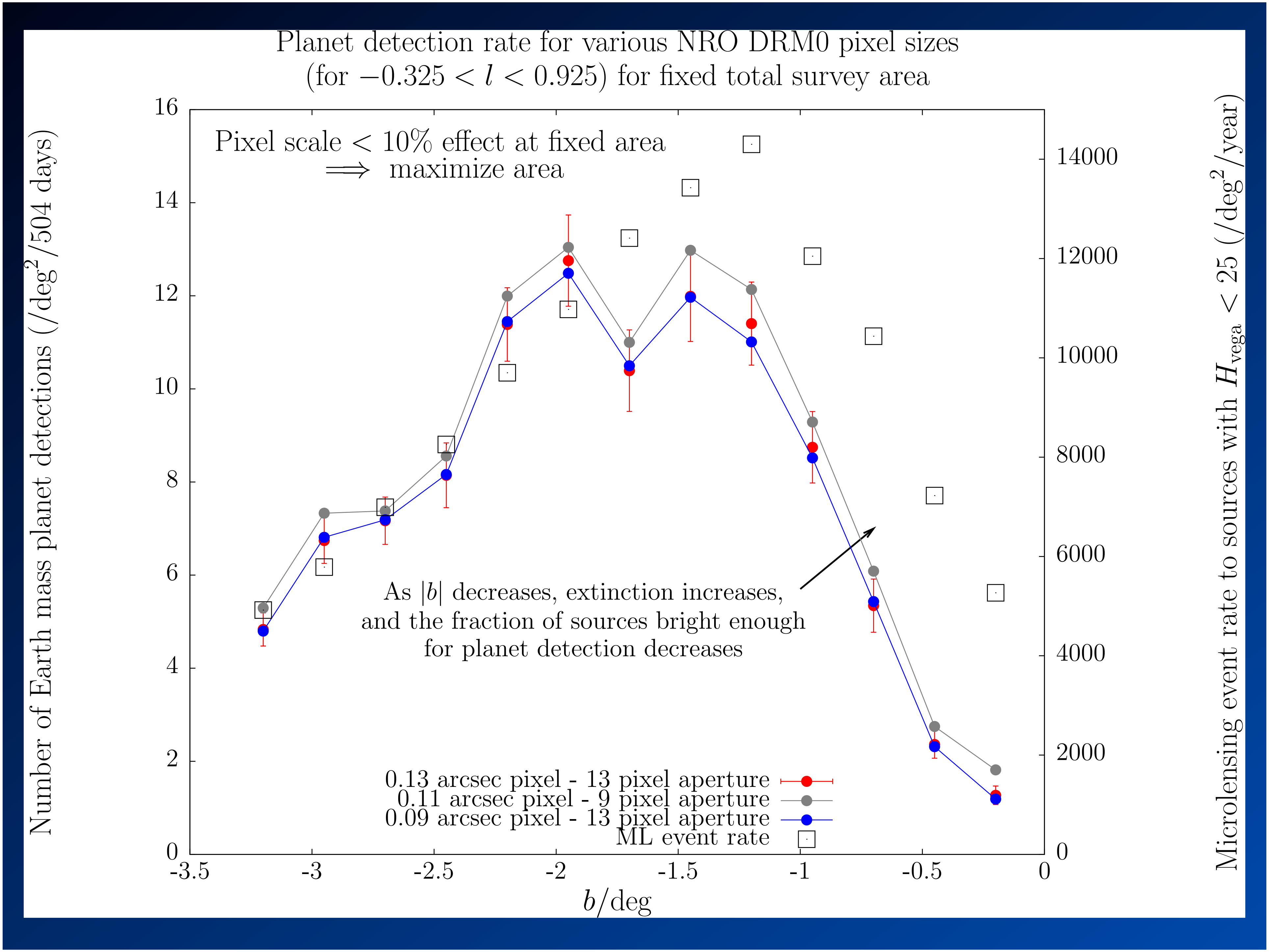
0.11"

0.13"

F087 deep stack - no dithering
texp=120x180s

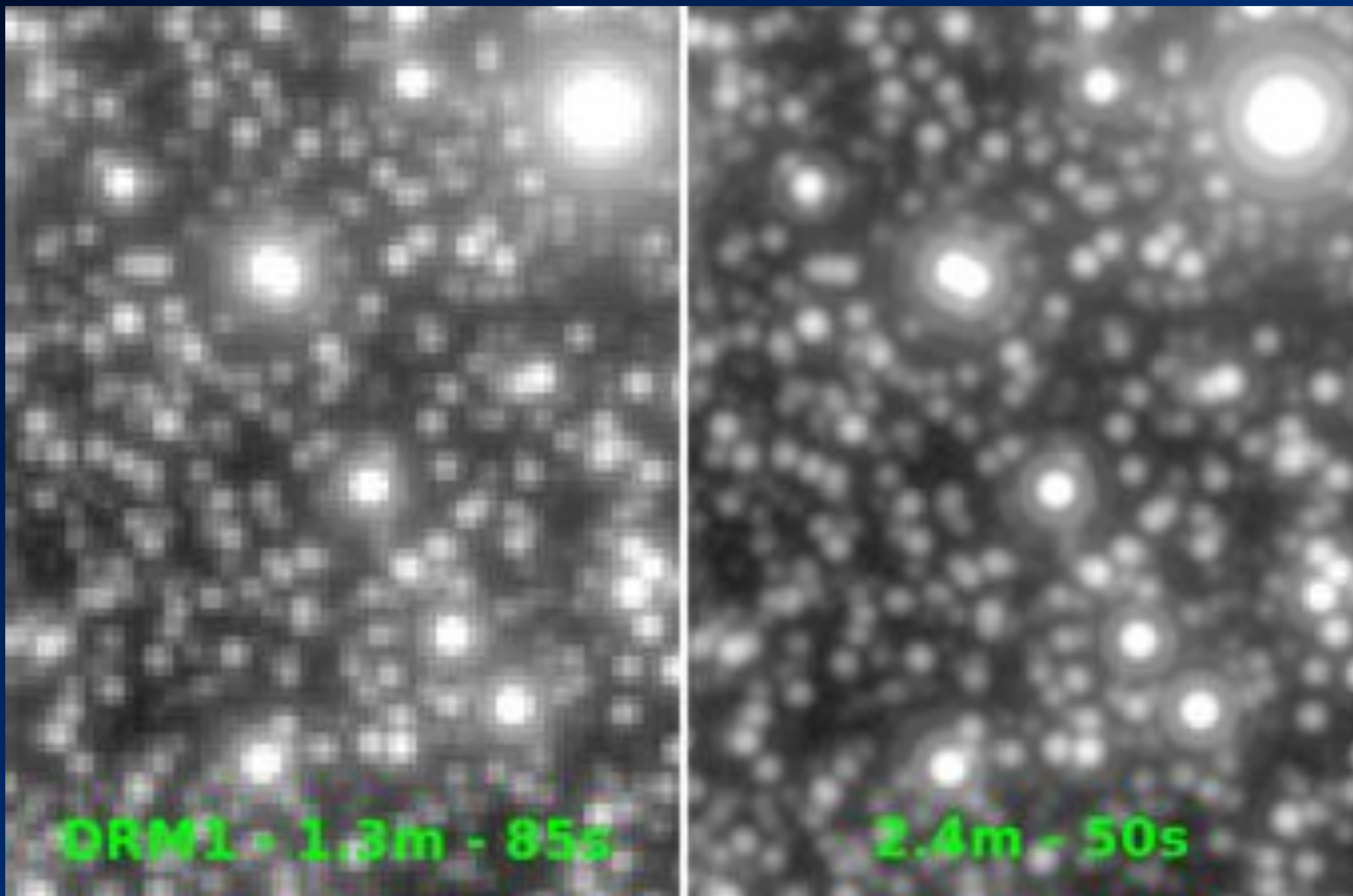


NRO 0.11"
DRM1 0.18"
NRO 0.09"
NRO 0.13"
N
W169
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
10
12
14
16
18
20
22
24
26
28



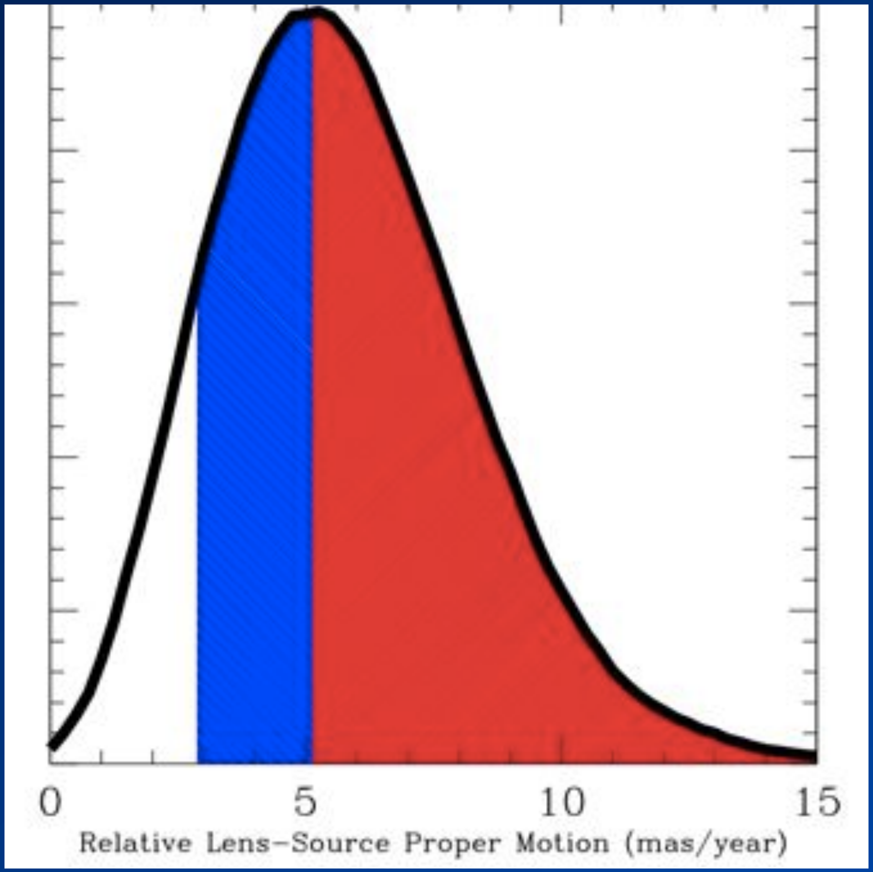
Planet detection rate for various NRO DRM0 pixel sizes
(for $-0.325 < l < 0.925$) for fixed total survey area
Pixel scale < 10% effect at fixed area
$\Longrightarrow$ maximize area
As $|b|$ decreases, extinction increases,
and the fraction of sources bright enough
for planet detection decreases
0.13 arcsec pixel - 13 pixel aperture
0.11 arcsec pixel - 9 pixel aperture
0.09 arcsec pixel - 13 pixel aperture
ML event rate
Number of Earth mass planet detections (/deg^2/504 days)
Microlensing event rate to sources with $H_{\rm vega} < 25$ (/deg^2/year)
b/deg
0
2
4
6
8
10
12
14
16
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0
2000
4000
6000
8000
10000
12000
14000

Resolution.



Characterization.

- Better resolution:
  - Fewer unrelated blends.
- And more photons:
  - Better centroid accuracy.
  - Better shape measurements.
  - Smaller proper motions.
- Currently proceeding with Fischer matrix + analytic estimates.



Issues.

- Event rate normalization and distribution.
- Field Optimization.
- Data Rate.
- Red cutoff.
- Habitable Planets?

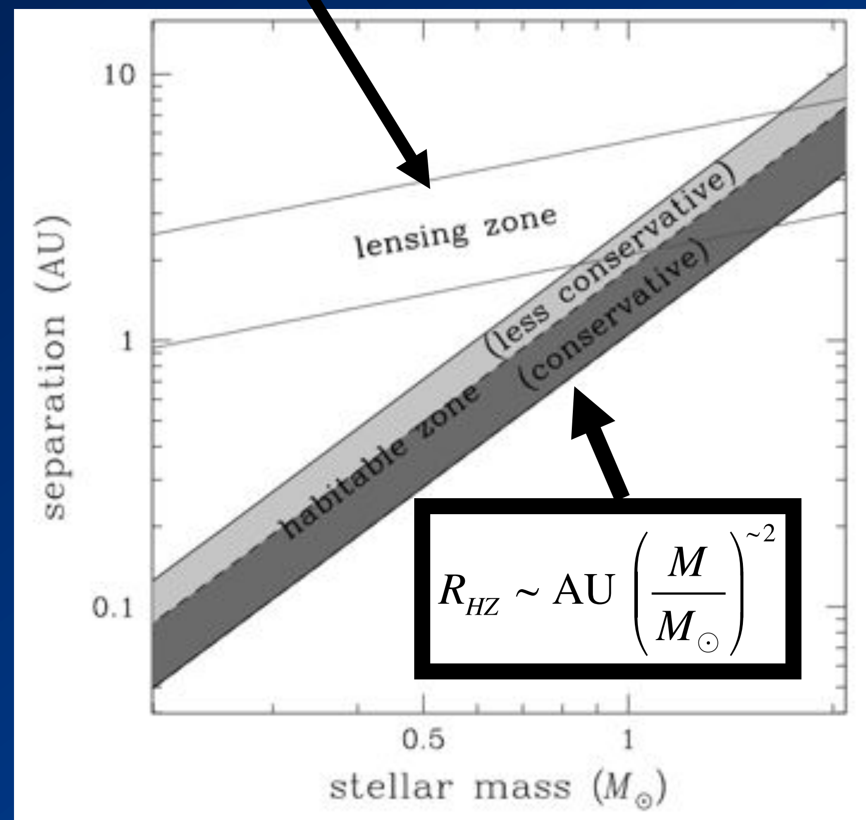
Limits: Habitable Planets.

- Habitable zone is well interior to the Einstein ring radius for most lenses.

$$\frac{R_{HZ}}{R_E} \sim 0.3 \left(\frac{M}{M_\odot}\right)^{\sim 3/2} [x(1-x)]^{1/2}$$

- Minor image perturbations.
- More sensitive to source size.
- Require better precision.
- Can be made up by more time through the “x” factor.

$$R_E = \theta_E D_l \sim 3.5\,\mathrm{AU} \left(\frac{M}{M_\odot}\right)^{1/2} [x(1-x)]^{1/2}, \quad x \equiv \frac{D_{ol}}{D_{os}}$$



$$R_{HZ} \sim \mathrm{AU} \left(\frac{M}{M_\odot}\right)^{\sim 2}$$

(Park et al. 2006)